Comparison the PD Current and PD Voltage for Two Cubical and Cylindrical Cavity in Solid Insulation Resin Epoxide

Bahaman Tavakoli and S. M. Hassan Hosseini

Abstract— *In many studies is shown that solid insulation isn't 100% perfect and there is a little impurity in insulation. These impurities presence as gas and air-filled cavities in production. The form of these cavities is cylindrical, cubical, triangular, elliptical and so on. With Cavities growing up partial Discharge magnitude is increased. In this work, Partial Discharge within the resin epoxide sample with creating a small cubical and cylindrical as an artificial void is studied. This paper for measuring PD voltage and PD current for two cubical and cylindrical voids is organized. With attention to the size of void in resin epoxide insulation, a cylindrical cavity with a height of 4mm and radius of 2 mm in cube sample (30 mm x 30 mm x 5mm) is used and with cubical void with width of 3 mm, length of 5 mm and height of 4 mm is compared. This investigation is consummate in void located in the center of insulation with 10 kV voltage and 50 Hz fundamental frequency applied. With attention to the gap between the electrodes Partial Discharge iteration - PD occurrence and FFT are analyses. In this study, partial Discharge activity within small cylindrical and cubical void with MATLAB software ODE environment (Ordinary Differential Equation) is simulated*.

Keywords— **Partial Discharge, void, resin epoxide, cubical, cylindrical, solid insulation.**

1. INTRODUCTION

With electrical network growing up, Partial Discharge can be a method for equipment quality assessed. PD is introduced as partially discharge inside the insulation that in long time makes insulation breakdown. Therefore, partial Discharge estimation can be a concentrated process in insulation condition. In power equipment, Insulation voids are one of the main reasons for PD creating and with according to kind and size of the voids it has been the most effect in partial Discharge characteristics. Partial Discharge can occur in different insulating medium such as solid, liquids and gaseous where PD measurement is gradually becoming an important preventing maintenance for power apparatuses with voltage level in higher than medium voltage. According to IEC 60270 [1] vocabulary a breakdown is an abrupt change of all or part of an insulating medium into a conducting medium resulting in an electric discharge. Normally PD happen in the poor points when electrical field in the void is more than electrical field in the insulator. Material Insulation specification, determined the impurity and quality degree. In other hand, PD detecting and measurement for life insulation forecasting is necessary [2,3]. Asima Sabet in [4] with use of traditional model (capacitor model) simulated resin epoxide sample and he investigated kind of the voids in different sizes. In this work PD activity due to presence of a small cylindrical and cubical voids inside a solid insulation material in high voltage power equipment is studied. C. Jou chen in [5] with a corrected model evaluation the measurement of voltage discharge in the solid insulation sample. This paper is focused on the result of the partial discharge in solid dielectric with high and medium voltage. H. Illias and et al in [6] explained that the electron generating rate is depend on voltage and frequency applied, with increasing the voltage applied the electron generating rate is raised and with increasing the frequency applied PD iteration is raised. Voltage increasing cause to void surface charge and accelerated the insulation deterioration. in [7] by J. Ganesha two necessary process: 1-free electrons in void surface for starting electron avalanche and 2-increasing voltage and field more than insulation field for PD starting was studied. L. Neimar and P.L. Lewin in [8,9] shows that change in lag time in resin and polymeric sample cause to irregular PD process where can be the reason for generating Partial Discharge random pulses. discharge occurrence is depending on 1) relative permittivity of dielectric 2) voltage distribution between the electrodes and 3) insulation specification location where PD is occurred. In this study with a complex model we are winnowed the different and effective part of discharge occurrence in cylindrical and cubical model. Morphological changes on the cavity surface are examined to determine of failure mechanism. Modeling and computer simulation of Partial Discharge in solid insulation are very useful to deeply understand the phenomena. Based on the proposed model a computer simulation was done, presented and 2 kind of the voids (cylindrical and cubical) are compare together.

2. CREATING VOID IN CENTER OF INSULATION AND PD STUDIES

As mentioned before IEC 60270[1] vocabulary told us a breakdown is an abrupt change of all or part of an insulating medium into a conducting medium resulting in an electric discharge. In Figure 1 a dielectric with creating a void in center of it is shown. With increasing the dielectric thickness dielectric strength is increased [10]. Partial Discharge because of applied voltage and size of void may change randomly during simulation

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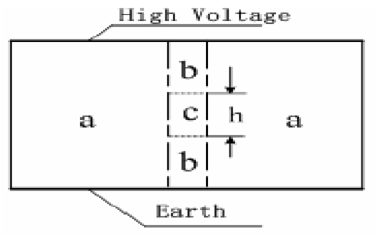

Fig. 1. Dielectric insulation sample with creating a void in Center of it. C-void in center of sample. B-Solid insulation h-Height of void. A-other part of insulation [16].

Breakdown is presence when field intensity in the void is more than gas breakdown and PD occurred in boundary between different *insulation* material, contamination and weak insulation condition. If U is the voltage between the electrodes and Q is the charge, therefore when discharge finished voltage is drop to $U - \Delta U$ and charge is converting to $Q + \Delta Q$.where ΔQ is transfer charge from external source. If Q=C.U in this condition $Q = C.U + \Delta Q$.If circuit impedance for related current with discharge is great. Then $C\Delta U$ is greater than ΔQ and $q \approx CU$approximately [12]. Electrical stresses caused by over voltages are generating an electric field which can be above material strength and depend on duration of stresses where can damage the insulation. In high voltage power equipment, the insulation failure take place is due to presence of PD inside the void enclosed to sample. PD activity usually observed in high voltage power equipment like transformers, cables and bushings. According to IEC 60270 apparent charge “q” of PD pulse is that charge which if injected in a short time between the electrodes of a test object would give the same reading on the measuring instrument as a PD current pulse itself [17]. There are 2 kind of voltage in partial Discharge 1) inception voltage: The voltage where PD starting and growing up 2) Extinction voltage: The voltage where PD is finished and PD magnitude is reduced where short time after its breakdown is occurred. Its studied that if the voltage stresses across the void exceeds the inception voltage of the gas within the void, then the PD activity will take *place*. Insulation specification for some material have Impurity in its quality. In other hand *Partial* Discharge detecting and measurement for life forecasting is necessary [2,3].

Void parameters are very important for PD characteristics and they are *convertible* in according to kind of voids. Some voids value is arranged here and other parameters like: radius, height are determinable. High conductivity in surface of void is cause of chemical and physical mechanism deterioration in surface of void after PD occurrence [13]. Figure 2 shows an ideal PD pulse. The pulse is characterized by rise time(Tr), is the time required to rise from 10% to 90% levels of peak value, decay time(Td) is the time required to decay from 90% to 10% levels of peak pulse value and pulse width time (Tw)is the time required for interval between 50% in both sides of peak pulses [5].

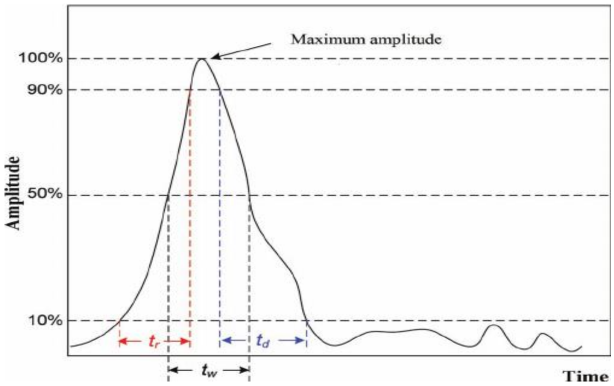

Fig. 2. PDpulsecharacterization [5].

When voids are raised the oscillation, frequency is increased but we are notice that partial Discharge magnitude in according to applied voltage and size of void in random form is adaptable [7]. For starting PD process 2 conditions are necessary. 1-free electrons in surface of void for starting electron avalanche process. 2-In according to increasing the voltage, field is increased, this voltage is call to U_{inc}.

3. STATISTICAL TIME LAG (TSTA)

When voltage is increased and lead to partial Discharge process (U_{inc}), there is an interval time between that and electron avalanche where its call to lag statistical time. This time in compare to voltage applied time is very short. We can ignore it for accelerating the process [14]. When our voltage is more than inception voltage and in that time PD isn’t starting, there is an interval time between both voltage where its call to lag statistical time and its symbol is T_{sta}. In attention to delay time PD is starting in voltages more than inception voltage. In high frequency, time between 2 PD occurrence in reason of small lag statistical time is reduced. In fact, when voltage in void is more than inception voltage PD is started. Electron generating rate is depend on voltage and frequency, so accelerating and increasing the electron generating rate is depend on the voltage and frequency increasing and in high frequency the number of PD iteration in each cycle is increased, rising the voltage can cause to accelerating the surface charge moving and deterioration the insulation [6].As the PD phenomenon is random in nature so the frequency appears for PD pulses is also fluctuating in nature.

4. PHYSICAL MODEL AND INTRODUCING IT FOR SIMULATION

First model in 1932 by Gemant and Philippoff were designed. This model was call to 3 capacitors model and its show in figure 3 [5]. This model for exact PD studies and with attention to other effective parameters on electrical field with purpose of electrical current discharge study was restructured, where its shown in figure 4[5].

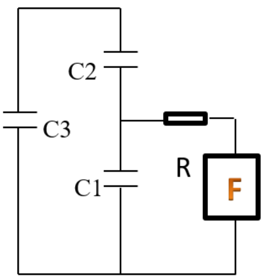

Fig. 3. Traditional model.

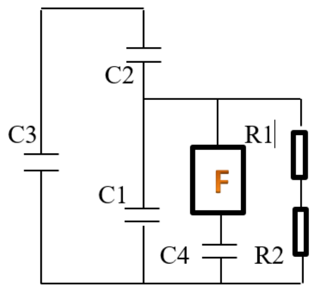

Fig. 4. Restructured model for exact PD study [5].

In [11] The model as showing in Figure 5, for Partial Discharge magnitude investigation in different Voids are analyzed.

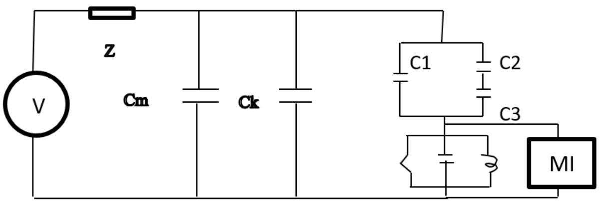

Fig. 5. Equivalent circuit for PD measurement in solid insulation [11].

In other hand purpose of this study is comparison the PD current and voltage for two cubical and cylindrical voids with use of figure 6 model, circuit designing for simulation done with according to figure 6. In this model for both cubical and cylindrical voids 10 kV voltage and 50 Hz fundamental frequency is applied. In this model, where C_m is measuring capacitor, C_k is coupling capacitor, C_1 is void capacitance, C_2 series capacitance with void, C_3 parallel capacitance, C_4 accumulation charge capacitance, RLC circuit is PD detector and F spark gap. In proposed model spark gap is model with a breaker. Timing for breaker closing 1/60 and breaker opening 1/55 is set. R_4, R_5 resistor for capacitor discharge are used.

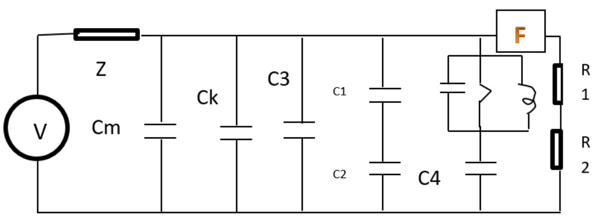

Fig. 6. The Proposed model for PD measurement.

In this model charge is calculated by [5].

$$Q = \frac{C_1 \times C_2}{C_1 + C_2} \times \frac{C_4}{C_1 + C_4} \times (U_1 - U_4) \quad (1)$$

$$U_F = U_1 - U_4 \quad (2)$$

where C_4 in this process by C_1 is starting to charge, this charge is continuing till both voltage equal together. When voltage in equation 3.2 is equal U_f a discharge is appearance. It happens when U_1 with inner peak voltage or U_4 changing (from discharge process in R_4) or both of them are occurrence [15].

Table 1. Related parameters to simulation[11]

Number	Parameter	Symbol	Value	Unit
1	Gap between the electrode	D	0.02m	M
2	Permittivity (resin epoxide)	ε_r	3.5	
3	Vacuum permittivity	ε_0	8.85×10^{-12}	F/M
4	Constant characteristics of gas	B	8.6	Pa
5	Pressure	P	105	N/m2

$$C_1 = \frac{\varepsilon_0 \times \varepsilon_r \times (a - 2b) \times b}{C} \quad (3)$$

$$C_2 = \frac{\varepsilon_0 \times \varepsilon_r \times 2r\pi}{C - h} \quad (4)$$

$$C_3 = \frac{\varepsilon_0 \times \varepsilon_r \times \pi}{h} \quad (4)$$

and C_4=1 PF [15]

In according to Pedersen model charge for cylindrical void is [9]:

$$Q = S \times V \times \varepsilon_0 \times \varepsilon_r (E_i - E_1) \times \Delta Z \quad (6)$$

where S is void geometric factor, V is volume of cylindrical void is given by $2\pi rh$ where r is cylindrical radius, h is void height; E_i is inception voltage, E_1 limiting field for ionization and Δz is distance between the electrodes is given by 1/d. .

With Using these equations E_i-E_1 value can rewrite as : [11].

$$\frac{Ei}{p} = \frac{El}{p}\left(1 + \frac{B}{\sqrt{2ap}}\right) \quad (7)$$

where B is gas constant characteristics, a is void radius, P is gas pressure in the void and gas in the void :E_1/P (for air =24.2 Pa.m). Inception voltage is depend on inception field.Inception field for a sample PD is depend on void geometric, gas pressure, dielectric permittivity and ionization process in the gas. in other hand inception field is calculated by [11]:

$$E_{inc} = (E_1/p)_{cr} p\left(1 + B\sqrt{pd}\right) \quad (8)$$

where $(E_1/P)_{cr}$ and B are related parameter to gas ionization, P is pressure in the void and d is void dimension

For air $(E_1/P)_{cr}$=24.2 $Pa^{-1}m^{-1}$ and B=8.6$\sqrt{pa.m}$.other circuit elements are listed in Table 2.

Table 2 : Other circuit element characteristics are[11]

Number	Equipment	Capacitance
1	Measurement capacitor	200/1500 PF
2	Coupling capacitor	1000 μf
3	Detecting circuit resistor	50 ohm
4	Detecting circuit inductance	0.63 mH
5	Detecting circuit capacitor	0.47 μf

5. SIMULATION

Primarily, we are starting simulation in 10 kV, 50 Hz for cubical void. With attention to before mention formula $C_1 = 2.079 \times 10^{-13}, C_2 = 5.420 \times 10^{-13}, C_3 = 30.6 \times 10^{-13}$ are calculated. Other simulation parameters like Table 2 are decided. PD voltage for cubical void as follows:

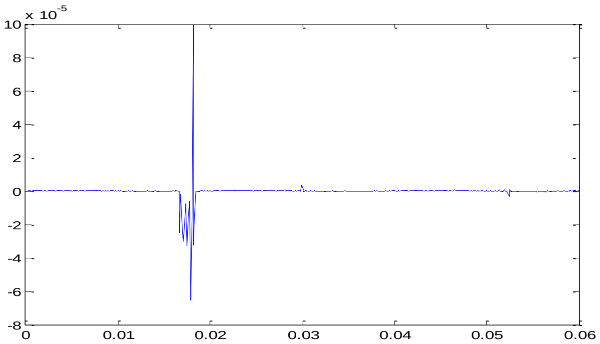

Fig. 7. PD voltage for cubical void.

This graph in 10 kV for 3 cycles (t=0.06) is simulated and maximum PD magnitude is:1.325×10^{-4}. In this study (simulation) instead of spark gap a breaker is used. The discharge is occurred in the first cycle and fourth quadrant. In same voltage source PD current measurement as follows:

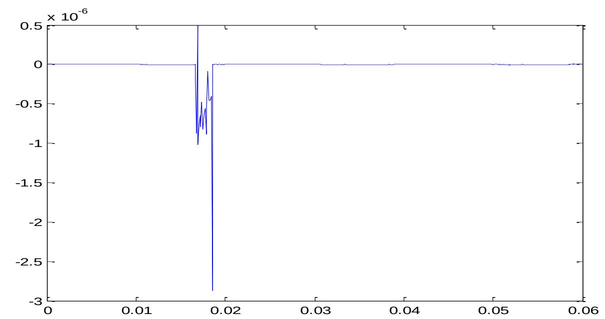

Fig. 8. PD current for cubical void.

As we can see in figure 8 PD current is 2.8×10^{-6}. In the next station simulation is doing for cylindrical void.

The Purpose of this study is comparison between cubical and cylindrical voids in according to proposed model. Then we continue the simulation in 10 kV voltage and 50 Hz fundamental frequency. The computational for cylindrical void in according to before mention formula : $C_1 = 4.83 \times 10^{-12}, C_2 = 3.89 \times 10^{-13}, C_3 = 2.78 \times 10^{-14}$ are calculate. The PD activity inside the solid insulation is highly depends on entire geometry of the void presence inside the solid insulation. In addition, PD is raised with raising the applied voltage but in this study the voltage is constant. The PD current for cylindrical void as follows:

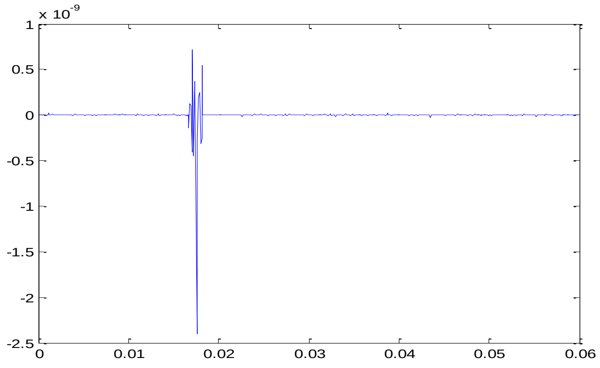

Fig. 9. PD current for cylindrical void.

PD magnitude in this measurement is equal to: 2.5×10^{-9}. This value is smaller than in compare to cubical void as showing in figure 9. PD voltage in cylindrical void as shown in figure 10.

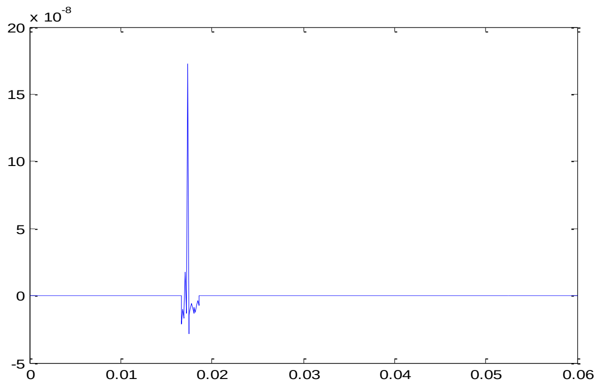

Fig. 10. PD voltage for cylindrical void.

As we can see PD magnitude is equal to 18×10^{-8} and its magnitude is drop in compare to cubical void. With increasing the voltage same result are simulated and distance between them is increased.

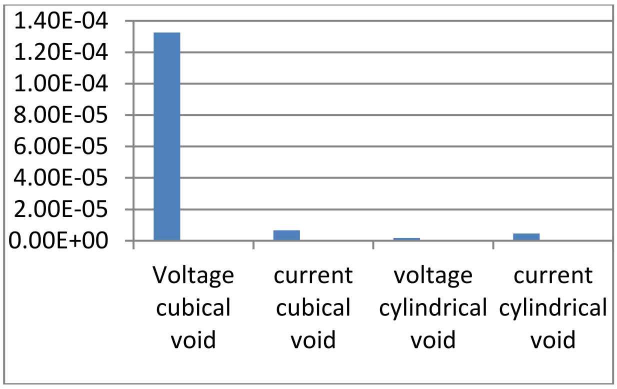

Fig. 11. Chart for comparison the void.

As we mentioned spark gap or gap between the electrodes for discharge with a breaker is simulated. In fact, the simulation results just showing the PD magnitude in timing. To identify the occasion of PDs with respect to the phase angle, phase resolved partial Discharge technique (PRPD) is elegant technique for monitoring power equipment. The presence of PD pulses in different quadrant gives the cause of occurrence of PDs [16,18]. In proposed model breaker closing time (1/60) And breaker opening time (1/55) are set. The difference time between them is 1.5 ms where discharge is appeared. With increasing distance (closing and opening breaker time) PD iteration or discharge time is increased and with change in time PD occurrence place is changed as showing in figures 12 and 14.

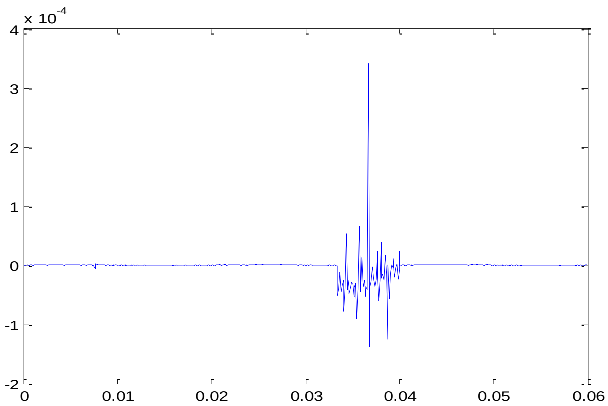

Fig. 12. Change presence in PD quadrant with change breaker time.

Frequency content of observed PD pulse in figure 12 with method of FFT analysis is presented in figure 13. It shows the frequency plot with applied voltage of 10 kV. Its presented that frequency is varies from 0 to 4.5 kHz. As the PD is random in nature so the frequency appears is fluctuating in nature. In figure 13 total harmonic distortion or THD is equal to 95.66%, whereas this index determines the quality of sinusoidal. Its shown that figure 12 is fluctuation completely.

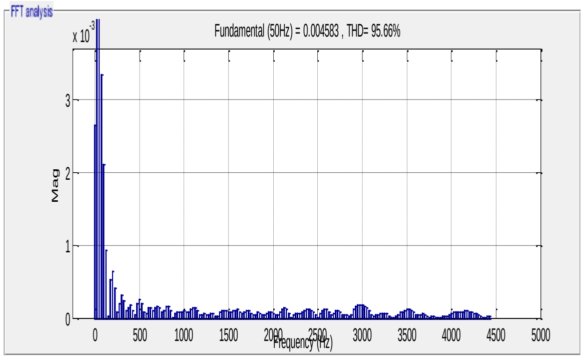

Figure13.FFT analysis for figure 12.

The breakdown strength is depending upon the space between the electrode, width - shape of electrodes and material used for insulation. The size and shape of electrodes are responsible for determination of the volume of the medium subjected to high electric stress[19]. Increasing in volume increases the impurity content particles. More impurity particles content lowers the breakdown voltage of the space between the electrodes [17]. In figure 12 breaker closing timing (2/50) and breaker opening timing (2/60). As we can see PD iteration because of time distance developing is increased and PD occurrence is displacement. PD is started in 0.033(2/60 breaker opening time) and is finish in 0.04(2/50 breaker closing time) in Figure 14, opening breaker timing is 13 ms and close breaker timing is 40 ms. In this figure PD occurrence is transfer to first and second cycle and discharge time is depending on distance time between opening and closing breaker time. In figure 12,14 in reason of increasing spark gap PD iteration is increased.

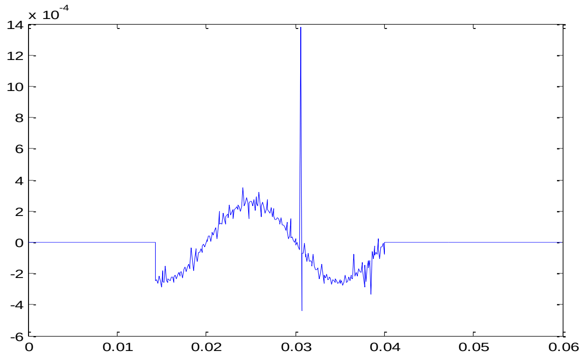

Fig. 14. Changes presence in PD quadrant with change in breaker time.

The maximum amplitude of frequency for Figure 14 appears in less than 200 Hz. Its observed that frequency because of time increasing is pressed. THD in Figure 14 is drop to 50.53%, where in compare to figure 12 is decreased. The main reason is because of time increasing with time increasing frequency fluctuating is dropped.

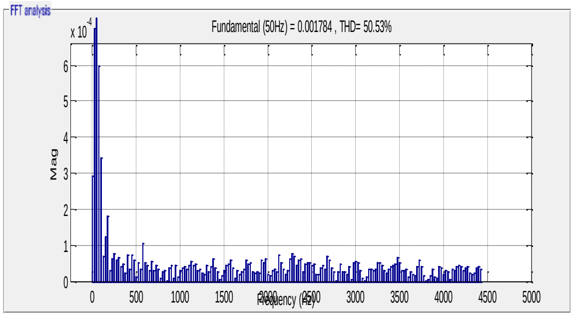

Fig. 15. FFT analysis for Figure 14.

6. CONCLUSION

In this study with creating 2 cylindrical and cubical voids PD current and voltage in the Simulink model are compared. Computer simulation is a very useful method for deeply understanding this phenomenon. As it observed PD magnitude in 10 kV for both voids are applied in the proposed model for a cubical void, PD magnitude in current 2.8×10^{-6} and PD voltage $1.325 \times 10^{-4}$are simulated. Simulation result (PD magnitude) for cylindrical void in PD current $-2.4 \times 10^{-9}$and in PD voltage 18×10^{-8} is simulated. In according to result for both cylindrical and cubical voids In PD current and voltage magnitude in cubical void is bigger than cylindrical void. Then in our result for proposed model cubical void is more danger than cylindrical void. In other hand with modeling spark gap with breaker, we observed with increasing distance time (closing and opening breaker time) PD iteration is much more and with time displacement PD occurrence is displaced. We can simulation partial discharge in solid dielectric with different physical model but comparison this simulation with measurement data is shown, each of these models are responsible for the different behavior of different defects.

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